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A current controlled converter with fault tolerant strategy

M.Sc. Thesis

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STATEMENT

This Thesis is submitted to Ain Shams University in partial fulfillment of the requirements for M.Sc. degree in Electrical Engineering.

The included work in this thesis has been carried out by the author at the department of electrical power and machines, Ain Shams University. No part of this thesis has been submitted for a degree or a qualification at any other university or institution.

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Abstract:

Many of researchers are interested in Pulse Width Modulated (PWM) rectifiers which play an important role in power conversion systems. PWM rectifiers have many advantages like unity power factor and directional power flow. Therefore, they are recently spread to be used for many applications such as electrical vehicles and active filters. Space Vector Modulation (SVM) based Hysteresis Current Control (HCC) is one of current control techniques which has important features that are discussed in this thesis. Therefore, we are interested in studying the current controlled PWM rectifiers with considering the SVM based HCC scheme. PWM rectifier reliability is important to be considered. Therefore, open switch fault detection and tolerant methods are required to improve system reliability. Fault tolerant methods are classified into methods based on software control and methods based on topology control which are presented in this thesis. The objective of this thesis is to analyze the open switch faults of PWM rectifiers in order to find an open-switch fault-tolerant strategy for current controlled (SVM based HCC scheme) PWM rectifiers. This fault-tolerant strategy should maintain the PWM rectifier reliability with less distortion. The suggested strategy is composed of two steps. The faulted zero voltage vector is compensated in the first step, while the faulted active voltage vectors are partially compensated. Then the angle between the reference current and reference voltage vectors is nullified in the second step of the suggested fault-tolerant strategy. The suggested strategy is simulated on EMTDC/PSCAD software package. Simulation results prove that the suggested fault-tolerant strategy succeeds to minimize the total harmonic distortion (THD) of the input currents during an open-switch fault. Also the current rating of each switch is obtained after applying the suggested fault tolerant strategy with respect to its rating value before applying the suggested fault tolerant strategy. The simulation results are verified by experimental work.

Key Words: PWM rectifier, SVM based Hysteresis Current Control, system reliability, open switch fault and fault tolerant control.

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List of abbreviations:

PWM:	Pulse width modulation.
UPS:	Uninterruptable Power Supply.
HVDC:	High Voltage Direct Current.
THD:	Total harmonic distortion.
SVM:	Space vector modulation.
CC:	Current control.
CC-PWM:	Current control pulse width modulation.
SVPWM:	Space vector pulse width modulation.
i_a, i_b and i_c:	line currents a, b and c.
i_{Aa}, i_{Bb} and i_{Cc}:	Reference line currents a, b and c.
ε_A, ε_B and ε_C:	Current error signals.
S_A, S_B and S_C:	Switching signals.
PI:	proportional integral.
HCC:	Hysteresis current control.
V_n:	Space voltage vector.
V_{zero}:	Zero voltage vector.
V^*:	Rectifier input space voltage vector.
V_r^*:	Reference space voltage vector of a PWM rectifier.
i_d, i_q:	Direct and quadrature currents respectively.
L:	Inductance of the output filter.
u_k:	The input space voltage vector of a PWM rectifier.
e:	The source voltage.
i^*:	The reference current vector
i_e:	The current error vector.
I_{3ph}:	The three phase current vector
τ:	The angle difference between the three phase current vector and the reference space voltage vector
$\varphi_{I_{3ph}}$:	The angles of the three phase current vector.
$\varphi_{V_r^*}$:	The angles of the reference space voltage vector.

Chapter 1

Literature Survey

1.1 Introduction

The PWM rectifiers are an important ac-dc converters which are used in many applications such as active filters, adjustable speed drivers, interfacing of renewable energy resources with a grid, hybrid or electrical vehicles, Uninterruptable Power Supplies (UPS) and High Voltage Direct Current (HVDC) transmission systems [1], [2].

They are widely used because they have many advantages like directional power flow, unity power factor and controlling the DC bus voltage [3],[4]; also they have nearly sinusoidal line currents with low harmonics which is considered a solution for mitigating the harmonics pollution [5],[6] and [7].

Power converters face a great challenge with faults; one of these faults is open switch faults that occur in power electronic switches (IGBTs and MOSFETs). Open switch faults degrade the converter performance and may cause whole converter damage. They can't be detected and isolated by using traditional methods and techniques of short circuit faults. Therefore, they need to open-switch fault detection and diagnostic methods to shut-down the converter or to activate fault-tolerant strategies.

A lack of reliability is one of the main problems of power electronics converters. After detecting a fault, the converter must be disconnected which may lead to partially or totally disconnecting of the electrical system. The sudden disconnection of electrical power may not be valid for critical applications such as financial markets, hospitals, military and offshore generation systems which are sometimes located far away from the shore. Their maintenance is frequently unsuitable, costly and even impossible [1], [8]. Therefore, open-switch fault-tolerant control methods are required to enhance system reliability and continuity of operation with reduced losses and acceptable THD.

Either software or topology based fault-tolerant control strategies are available for PWM rectifiers. A software based fault-tolerant strategy depends on modifying PWM switching patterns and their switching times [9], while a topology based fault-tolerant strategy reconfigures the converter after isolating the faulty switch.

This thesis presents a fault tolerant strategy for open switch faults of SVM based hysteresis current controlled three phase PWM rectifiers. The suggested fault-tolerant strategy improves the performance of the PWM rectifier in case of existence of an open-switch fault by reducing the THD of input three-phase currents, subsequently, reducing the total harmonics of the ac grid current. Therefore, the probability of secondary faults is reduced and the reliability of PWM rectifier is increased.

The suggested fault-tolerant strategy has many attractive features such as easy to implement, low cost where no hardware circuits are needed, and improved waveform quality.

1.2 Voltage and current controlled PWM converters

Voltage source PWM converters can be operated as voltage controlled converters or current control converters [10]. Voltage controlled converters aims to adjust the amplitude and phase of converters voltage with respect to the grid voltage for controlling the flow of power between the converters and the grid [11].

The control techniques of PWM converters can be classified into voltage-based and virtual flux based. Reference [5], presents and compares between four types of these techniques which are voltage oriented control (VOC), voltage-based direct power control (V-DPC), virtual-flux oriented control (VFOC) and virtual-flux-based direct power control (VF-DPC).

Also voltage oriented control (VOC) and direct power control (DPC) are presented in [6]. There are other PWM techniques which are used for voltage controlled converters such as carrier based PWM (sinusoidal PWM and CB-PWM with Zero Sequence Signal (ZSS)) and space vector modulation [12], [10]. Also there are advances in pulse width modulation techniques which provide fundamental amplitude more than normal sinusoidal PWM, low harmonics and eliminating of specific harmonics. These techniques include trapezoidal modulation, staircase modulation, stepped modulation and harmonics injected modulation [13].

Current controlled PWM (CC-PWM) converter as shown in Fig. 1-1 comperes between the instantaneous currents feedback i_a, i_b and i_c with reference currents i_{Aa}, i_{Bb} and i_{Cc} to